Tractable Transmission Topology Control

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Objectives

In this talk, we will discuss tractable control of the transmission network topology, to

- Increase the value extracted from existing transmission capacity
- Reduce the need for new transmission capacity
- Lower generation costs
- Increase system reliability
- Provide additional controls to manage congestion (especially that caused by variable generation)

Optimal Power Flow (OPF)

- Objective: select the production level of each scheduled generator for the single interval of interest so as to minimize the total operation costs
- Constraints
  - — generation
  - — transmission
- Model formulated so that all variables are continuous

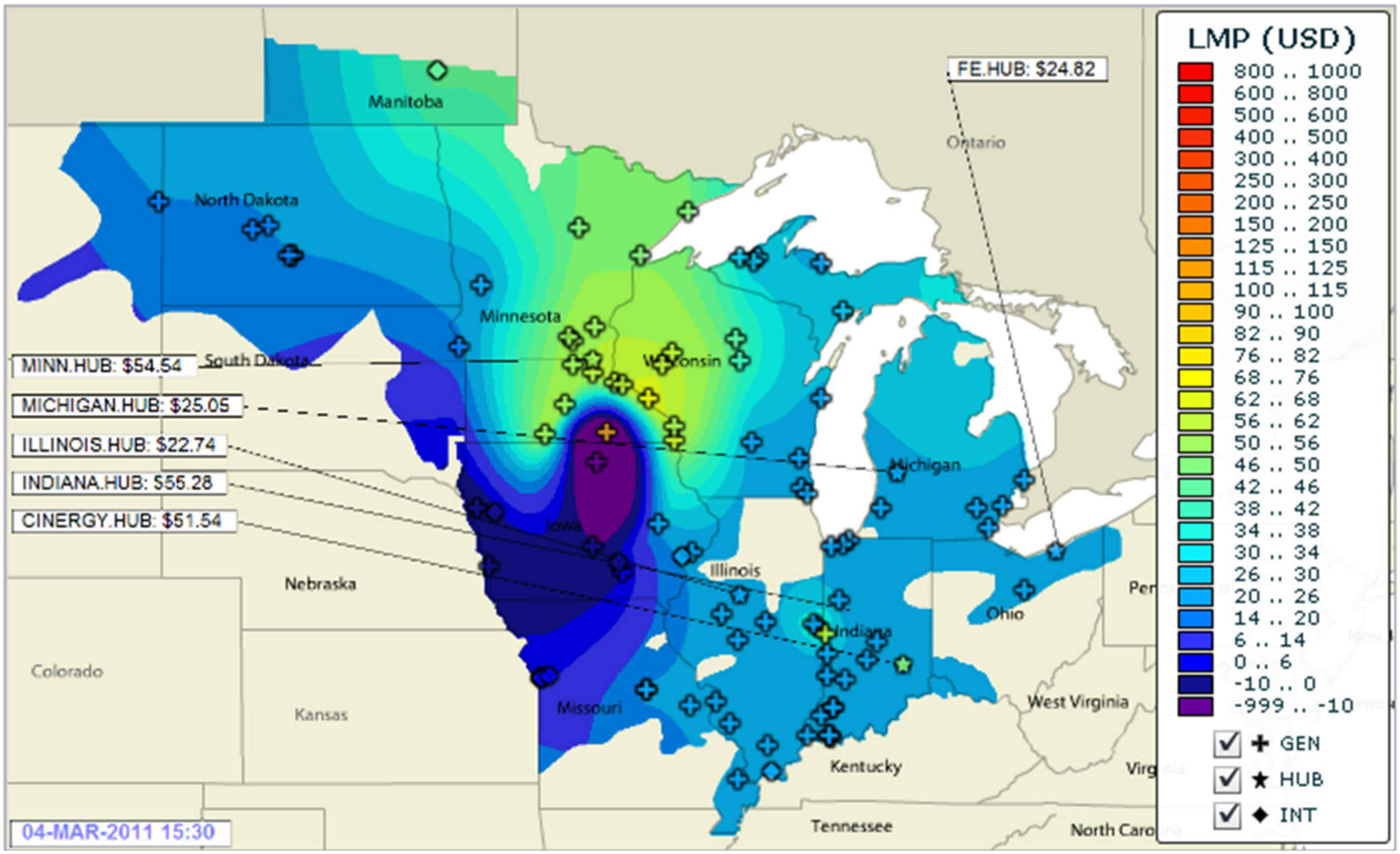
OPF: No Transmission Constraints

- The optimal OPF solution employs the **economic merit order**: fully dispatch units starting from most economic to least economic, until supply equals demand
- There is a single unit not at a capacity limit (*marginal unit*), whose cost sets the system-wide marginal price

OPF: Transmission-Constrained

- The economic merit order dispatch is not feasible,
- Some low-cost units have to decrease their production, while some high-cost units have to increase their generation
- **US production costs** increase by several billion dollars annually due to congestion
- Number of marginal units equals number of binding transmission constraints +1
- Marginal cost becomes dependent on location

Midwest ISO Real-Time Prices (3:30)



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source: www.midwestiso.org

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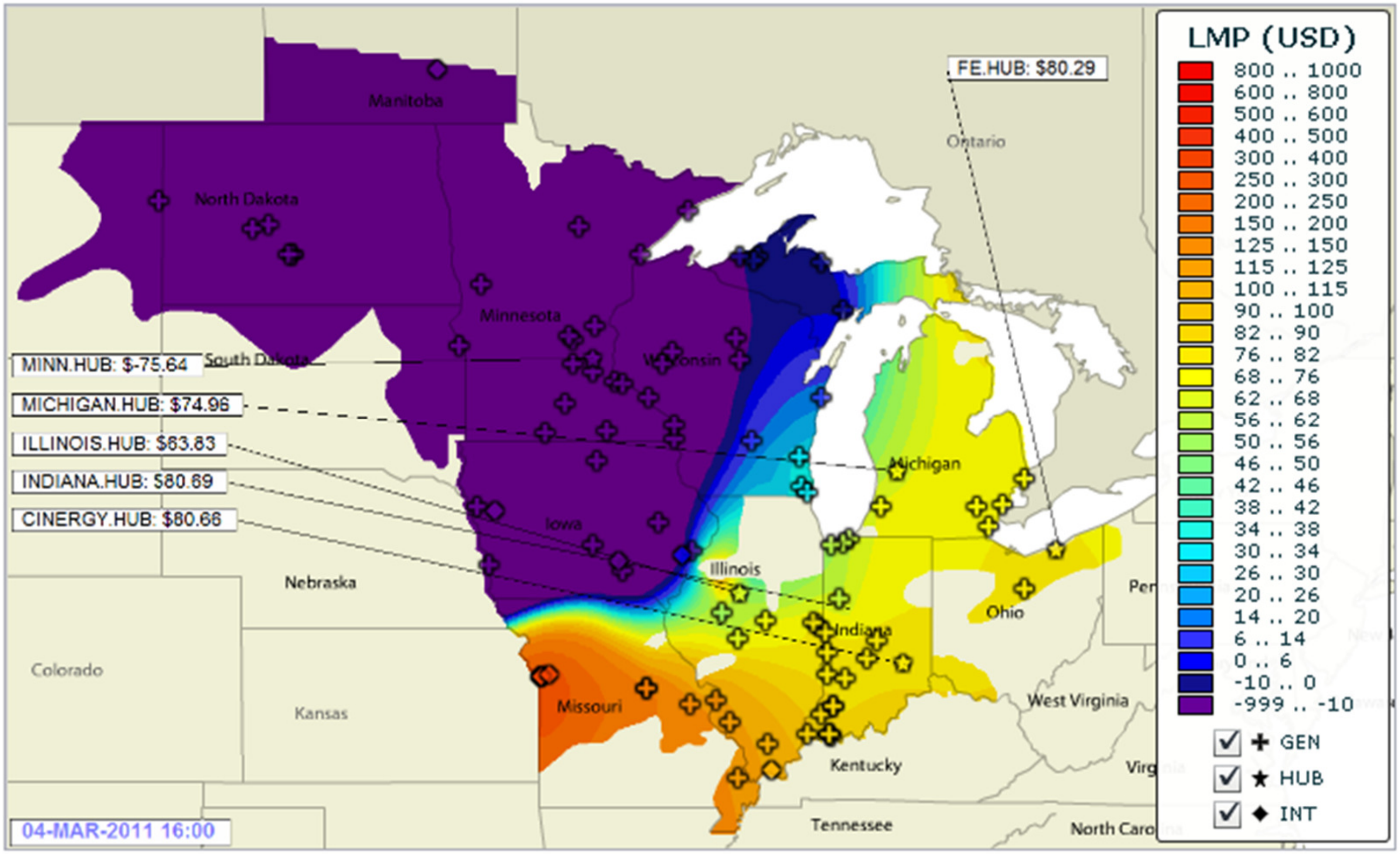
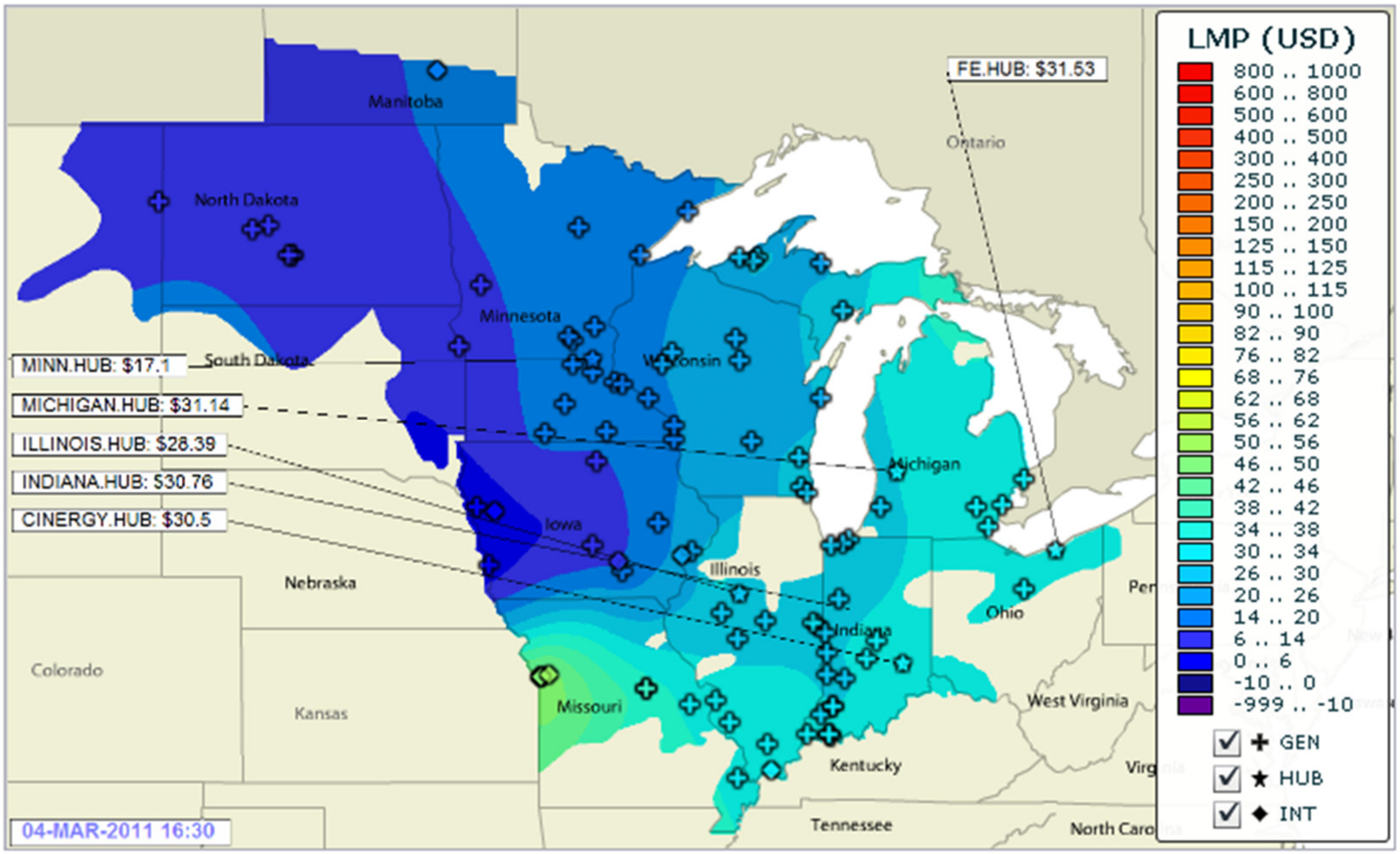
Midwest ISO Real-Time Prices (4:00)



source: www.midwestiso.org

Midwest ISO Real-Time Prices (4:30)

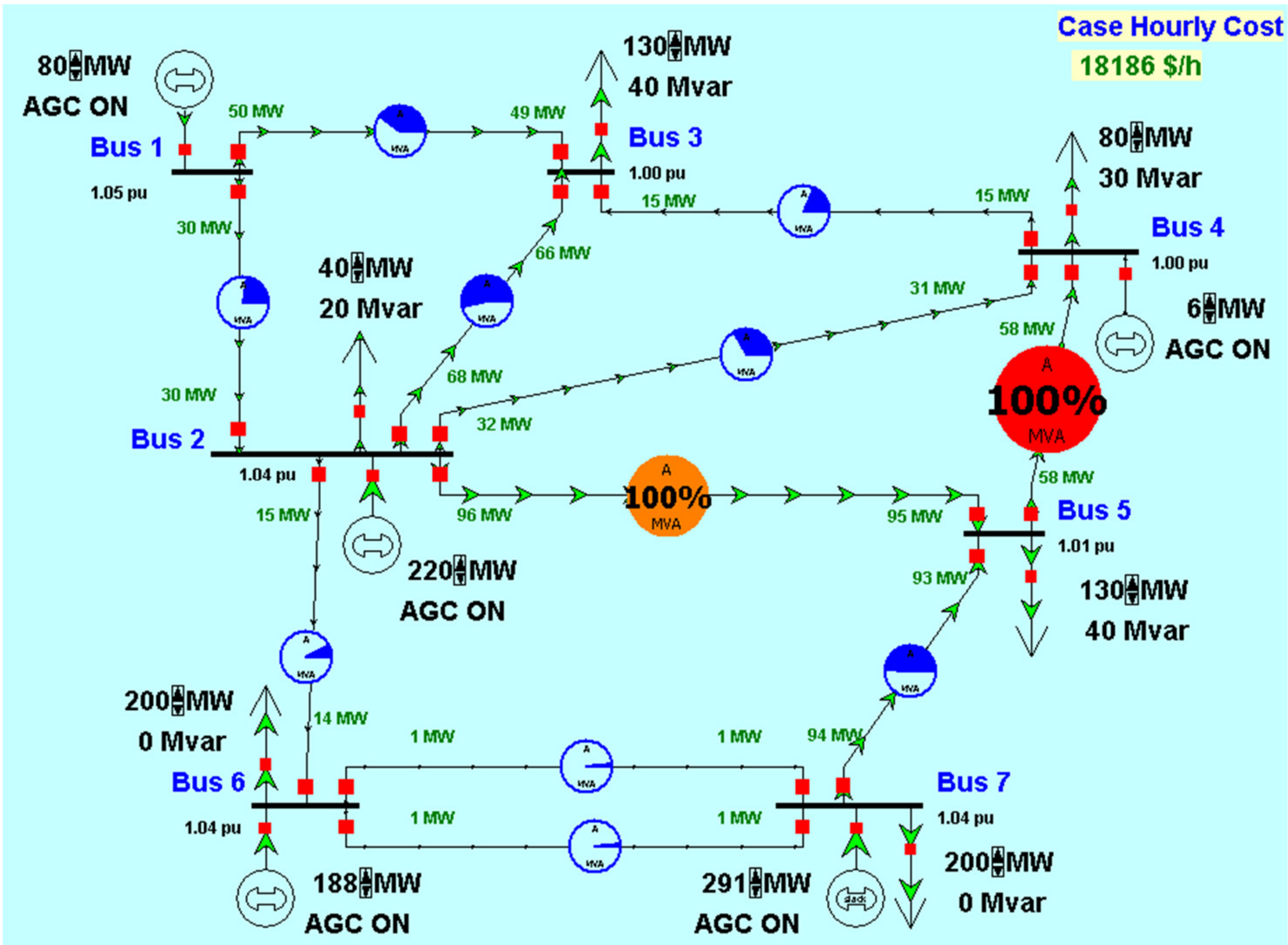


source: www.midwestiso.org

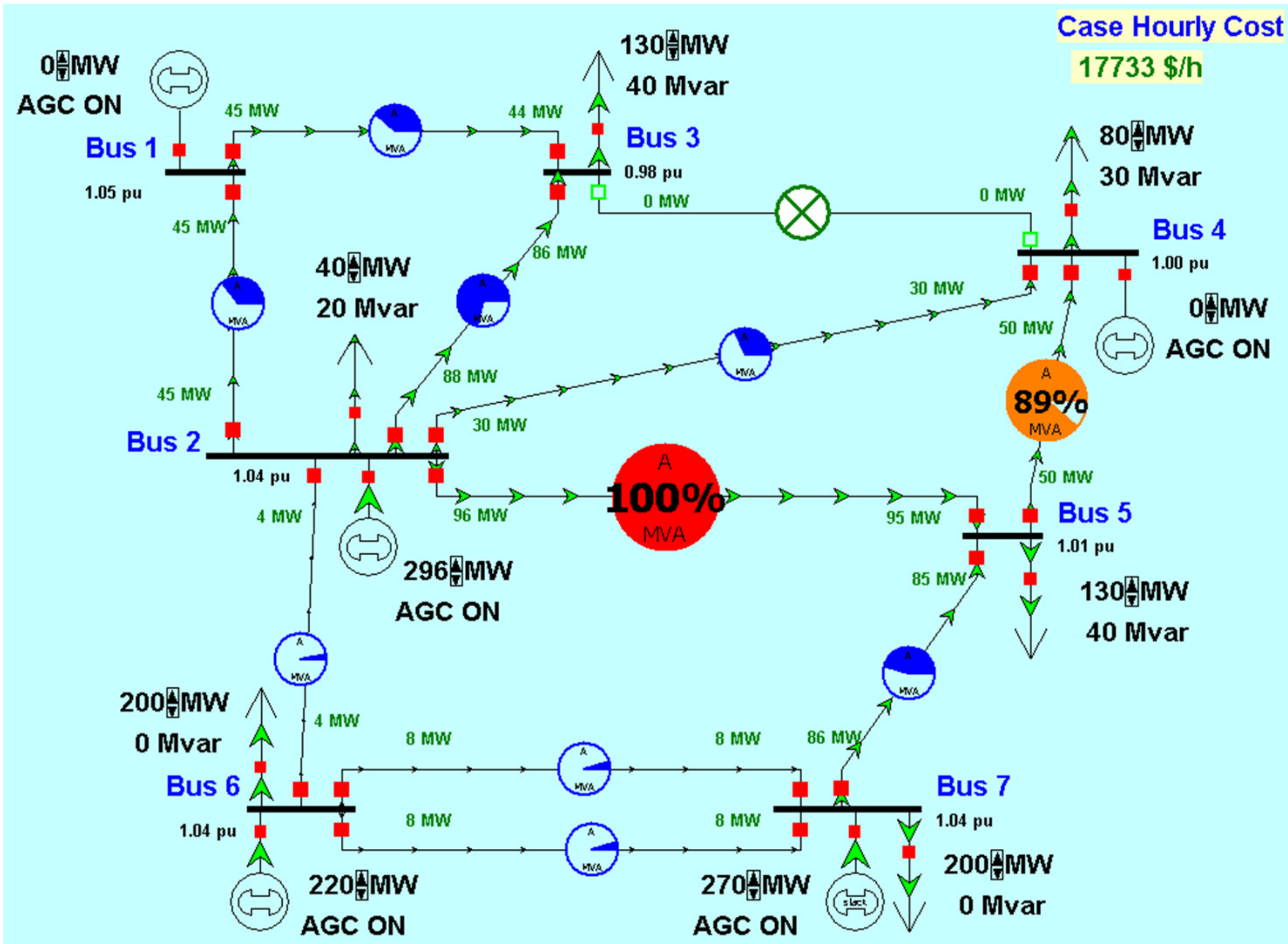
AC Power Flows

- Power flows distribute over the transmission network according to **Kirchoff's Laws**: inversely proportional to path impedance
- To control flows, one needs to
  - re-dispatch generation
  - control effective impedances
- Few transmission branches have flow control devices
- All branches have switches which can connect or disconnect the branch

7-bus Example: All Lines Closed



7-bus Example: Line 3 – 4 Opened



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Transmission Topology Control

- By switching transmission elements on or off, the network impedance can be discretely controlled so that the transfer capacity between low-cost resources and loads is maximized
- The branch states can be added to the OPF as decision variables, converting the OPF into a **MIP**
- Given the size of real systems and solution time requirements, MIP OPF formulations are computationally intractable

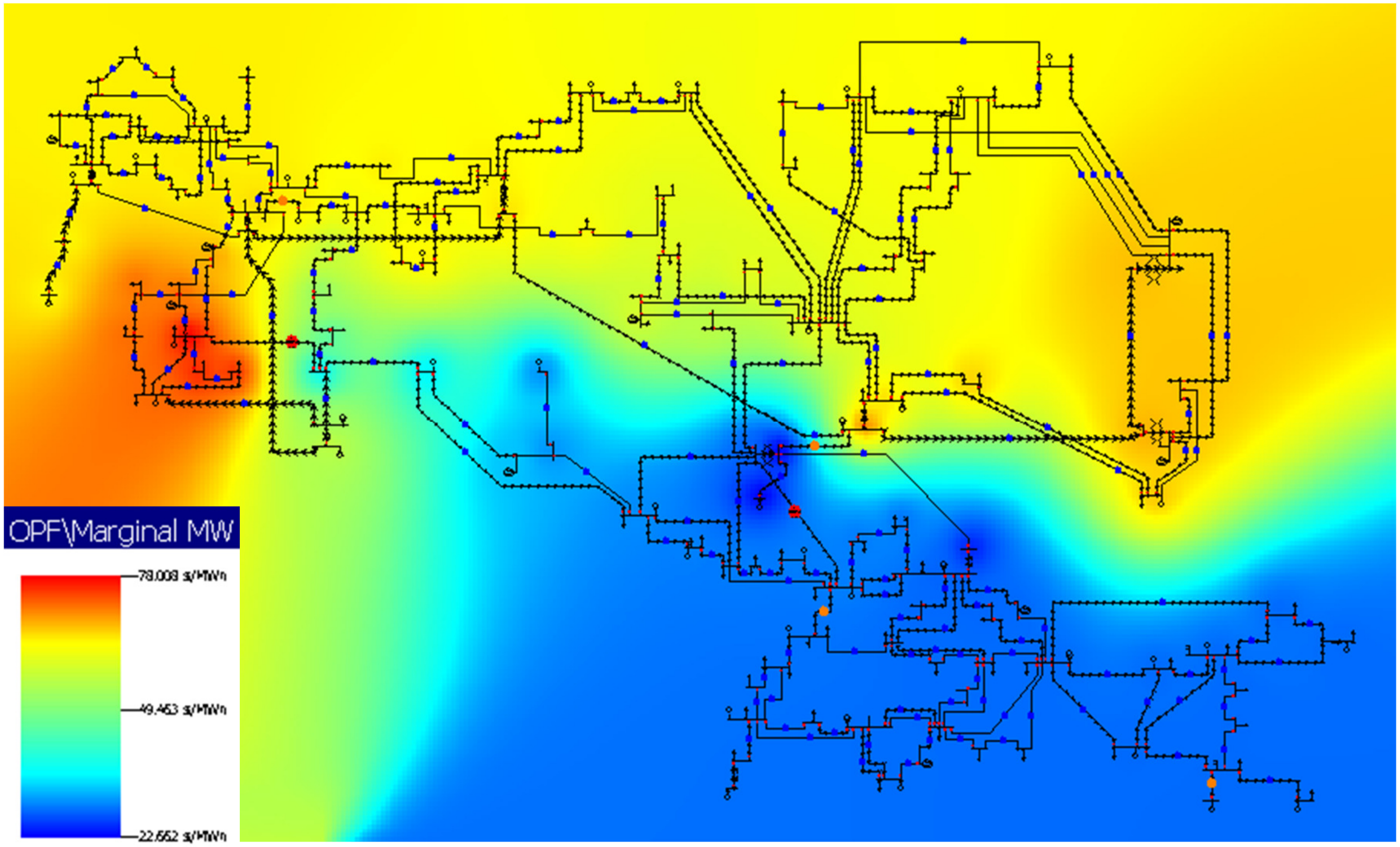
Topology/Dispatch Requirements

- **OPF feasible**: all demand is supplied and there are no overloads
- **Cost-reduction**: transmission topology changes allow a lower out-of-merit cost dispatch
- **Reliability requirements**: redundant connections (system can withstand outages)
- **Connectivity requirements**: disconnecting transmission elements does not cause system separation (islanding)

Tractable Policies

- To significantly reduce the computational time while providing near-optimal savings, we employ sensitivity-based iterative heuristic policies for transmission topology control
- These policies:
  - ✓ ensure feasibility
  - ✓ enforce security constraints
  - ✓ maintain system connectivity (no islanding)

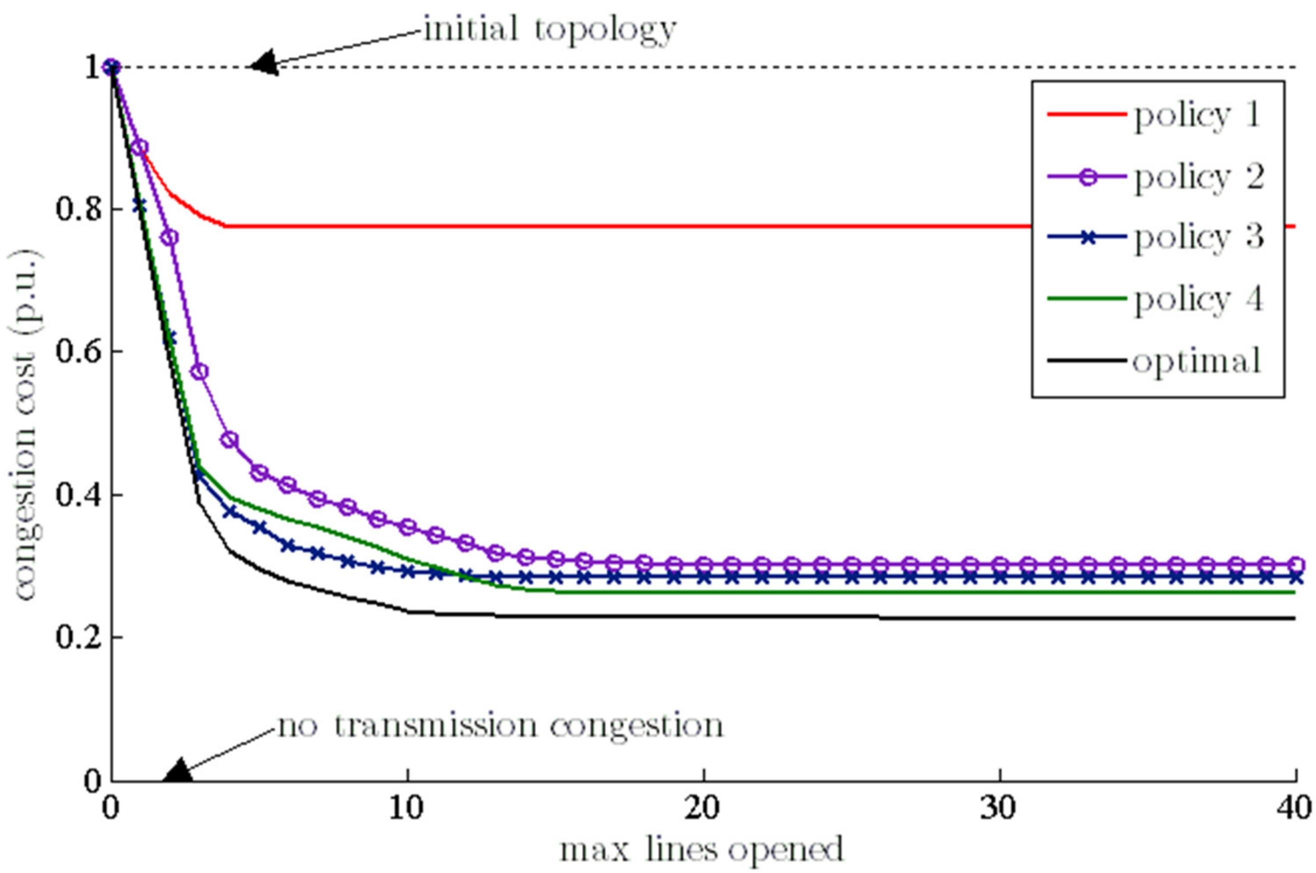
IEEE 118-bus Test System



118-bus System Simulations

- Topology represents a portion of the AEP system circa 1962
- 118 buses, 54 generators, 194 branches (all connected)
- Monte-Carlo simulation, 100 samples of available wind power and fuel cost realizations
- **Congestion costs 9.49%** of the production costs with initial topology

Mean Congestion Cost



118-bus System Simulations

metric	initial topology	copper plate	optimal	policy 1	policy 3	policy 4
expected cost (k$)	129.7	117.4	120.5	126.9	121.2	120.6
expected savings (%)	n/a	9.3	6.9	2.1	6.4	6.6
min / max savings (%)	n/a	1.0 / 19.2	0.8 / 11.3	0.3 / 4.9	0.7 / 11.2	0.6 / 10.6
savings w/ 10% wind forecast error (%)	n/a	9.3	6.5	2.1	6.2	6.4
lines disconnected (median)	n/a	n/a	22	4	16	21
av. opened flow (%)	n/a	n/a	28%	58%	28%	26%
open lines in optimal topology	n/a	n/a	100%	36%	56%	52%
expected computation time (s)	0.004	0.003	3 - 3600	0.55	0.33	0.42

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Summary

- Transmission congestion increases production costs
- Topology control can be effectively used to minimize these cost increments while maintaining reliability, but computational costs are high, due to integer variables
- We developed tractable algorithms that use sensitivity information to select promising candidate lines for switching
- The sensitivities employed indicate cost reductions while maintaining connectivity requirements
- Preliminary simulation results are very promising

Concluding Remarks

- Potential benefits of transmission topology control are very large
  - Production cost savings
  - Reduce transmission investment costs
  - Add flexibility in operations
  - Increase the ability to incorporate variable resources (wind, solar)
  - Increase reliability

Questions?

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